THE APOLLO 16 MARE COMPONENT: PETROGRAPHY, GEOCHEMISTRY, AND PROVENANCE. R. A. Zeigler, L. A. Haskin, R. L. Korotev, B. L. Jolliff, and J. J. Gillis, Dept. of Earth and Planetary Sciences, Washington University in St. Louis, Campus Box 1169, 1 Brookings Dr., St. Louis, MO 63116 (zeigler@levee.wustl.edu).

Introduction: The A16 (Apollo16) site in the lunar nearside highlands is 220 km from the nearest mare. Thus it is no surprise that mare basalt samples are uncommon at the site. Here, we present the petrography and geochemistry of 5 new mare basalt samples found at the A16 site. We also discuss possible provenances of all A16 mare basalt samples using high-resolution global data for the distribution of Fe and Ti on the lunar surface derived from Clementine UV-VIS data [1-2].

Background: The maria nearest to the A16 site are Sinus Asperitatis (220 km) and Mare Nectaris (~400 km). The A16 regolith consists of basin ejecta from Nectaris and Imbrium, and possibly Serenitatis, mixed with pre-Nectarian regolith [3-4]. Two formations were sampled at the A16 site, the Cayley Formation and the more feldspathic Descartes Formation sampled at North Ray Crater (NRC). Only 20 small samples of crystalline mare basalts have been reported from A16 [5-10]. Most A16 mare material occurs as glass in the finest soil fractions [5,11]; estimates of the fraction of mare material in the <1 mm fines range from 5-6 % [12-13].

Descriptions: Sample 60503,22-7 is a high-Ti basalt (~9 % TiO_2; Table 1) with ilmenite, olivine, a trace of Cr-spinel and Fe-metal, and xenocrystic olivine and pyroxene in a glassy matrix. Its REE-pattern and Cr, Sc, Sm, and Ba concentrations [14] are similar to those of A17 high-Ti basalts, but the TiO_2 concentration is slightly less. Sample 60603,10-16 is a very-high-Ti (VHT) basaltic vitrophyre with ilmenite, olivine, and Cr-spinel grains in a glassy matrix. Its major- and trace-element composition is consistent with VHT picritic glasses such as A12 and A14 red-black glass [15]. Sample 62243,10-22 is a very-low-Ti (VLT) vitrophyre with one area of rapidly crystallized, aluminous pyroxene. Its bulk chemical composition is similar to those of A17 VLT mare basalts. Sample 65703,9-13 is a VLT basalt with plagioclase, pyroxene, and olivine, and trace fayalite, Cr-spinel, troilite, and ilmenite. Its chemical composition is similar to Luna 24-like VLT mare basalts except its REE-pattern which does not match. Sample 60053,2-9 has a high-Al basalt composition, similar to A14 group 5 high-Al basalts [16]. It is composed of plagioclase, pyroxene, ilmenite, and a silica phase, with trace amounts of troilite, and an area of silica-hedenbergite-fayalite mesostasis (symplectite).

Discussion: The mare basalt fragments previously found at the A16 site are of three types: A17-like high-Ti basalts, A12-like low-Ti ilmenite basalts, and Luna 16-like high-Al basalts [5-10]. A16 picritic glasses are of two types: Apollo 15-like green VLT glass and A17-like orange high-Ti glass [5,11,15]. Of the 5 new samples reported here, only 60503,22-7 falls into one of these groups. Given the small particle size and lack of chemistry, many of the low-Ti basalts previously reported may be similar to our VLT samples 65703,9-13 and 62243,10-22. High-Al basalt 60053,2-9 and the high-Al basalts previously reported from A16 samples are similar only in being aluminous and low in TiO_2. The VHT picritic glass 60603,10-16 is unlike anything previously reported from the A16 collection.

Transport mechanisms: We propose that the mare basalts found at the A16 site were transported there through post-basin lateral mixing. Other potential methods do not seem feasible: **Pyroclastic eruption:** According to theoretical models, pyroclastic eruptions have an effective eruption limit of <300 km [17], less than half the distance to the nearest known pyroclastic deposit. **Basin ejecta:** Most of the mare basalts on the Moon were erupted post 3.9 Ga, precluding their inclusion in basin ejecta. A few ancient "cryptomare" basalt fragments (>3.9 Ga) occur as clasts in A14 and A17 breccias [15,18], but they are rare lithologies at both sites and do not seem to be significant components of basin ejecta.

Not indigenous to the A16 site; ARB: Ancient regolith breccias (ARBs) in the A16 collection have formation ages ~4 Ga, based on their noble gas compositions [19]. The ARB are feldspathic and contain Th-rich impact-melt breccias (IMBs), but have no trace of mare basalt or pyroclastic glass [19,20]. The high-Th IMBs are most likely Procellarum KREEP Terrane (PKT) material, deposited as Imbrium ejecta [21]. Thus, the ARBs likely formed during the formation of the Cayley Plains from a mixture of Imbrium and Nectaris ejecta and pre-Nectarian regolith, before any appreciable amount of lateral mixing at the A16 site had occurred. The lack of basaltic material in the ARBs makes the A16 mare basalts and pyroclastic glasses post-basin in age. **NRC:** The mare-poor nature of the A16 site prior to post-basin lateral mixing is further supported by the samples collected at stations 11 and 13, on a ray and at the rim of the young North Ray Crater [20,22,23]. This crater excavated materials that had been closed to lateral mixing since their deposition.

Lateral mixing*:* The lack of mare material in A16 samples that have been closed to post-basin lateral mixing suggests that the entire ~6% mare component that has been modeled in the bulk Cayley soils [13] results from post-basin lateral mixing.

By comparing FeO and TiO_2 concentrations of the A16 mare samples with global FeO and TiO_2 data sets of Clementine [1-2] and the global FeO data set from Lunar Prospector [27], it is possible to postulate on the most likely source regions of the A16 mare samples.

High-Ti mare basalt: The nearest high-Ti mare basalt flows to the A16 site are in southern Mare Tranquillitatis, about 300 km northeast from the A16 site. The two next nearest high-Ti mare basalt flows are ~600 km to the north in Mare Vaporum and ~750 km to the west in Mare Nubium. These flows are less extensive and have lower TiO_2 concentrations than M. Tranquillitatis, however. Mare Tranquillitatis is thus the most likely source region for A16 high-Ti basalts. Several 10-30 km Eratosthenian and Copernican craters are found in this region (e.g., Ross, Arago, Dionysius, Maskelyne, Moltke) and could be the source craters.

VHT picritic glass: The source of VHT picritic glass sample 60603,10-16 is more difficult to pinpoint. The current Clementine FeO and TiO_2 equations [1-2] are not calibrated for pyroclastic glass deposits. A large regional pyroclastic deposit occurs just south of Mare Vaporum (~600 km north) and smaller, local pyroclastic deposits ~500 km away in Alphonsus crater and along the northern and southern edges of Mare Nectaris [28]. Although the TiO_2 concentrations of these deposits are unknown, their low albedo implies high-levels of TiO_2 and FeO. It is likely that the larger pyroclastic deposit near Mare Vaporum is the source, as its surface area (~10,000 km^2) is vastly greater than the regional deposits (<100 km^2), and thus much more likely to be struck by an impact.

Low-Ti basalts: The low-Ti mare basalt flows nearest to the A16 site are in Sinus Asperitatis and Mare Nectaris. The next nearest low-Ti mare basalt flows are in Sinus Medii (~500 km) and in Mare Vaporum (~650 km). Based solely on distance, Sinus Asperitatis would be the most likely source region for low-Ti mare basalt at the A16 site. An important factor supporting Mare Nectaris or Sinus Asperitatis as source regions for the A16 low-Ti basalts is the 100-km Copernican crater Theophilus ~275 km east of the A16 site which hit the edge of Mare Nectaris and Sinus Asperitatis. Theophilus secondary craters within 10 km of the A16 site have been mapped [29], so the Theophilus impact surely delivered material to the A16 site, some of which would likely have been mare material.

VLT basalts: Clementine UV-VIS derived global TiO_2 maps have a detection limit of about 1 wt %. Distinguishing VLT basalts (<1 wt% TiO_2) from some low-Ti basalts (1-5 wt% TiO_2) is difficult at best. Only one large expanse of VLT basalt has been mapped, Mare Frigoris, but M. Frigoris is nearly 1500 km away, making it an unlikely source region. Mare Nectaris and Sinus Asperitatis have 2° TiO_2 pixel values in the 2.7-3.1 wt% range. This range is too high for VLT basalt, but it is comparable to large regions of M. Crisium and M. Serenatatis, the presumed sources of the VLT basalts in the Apollo and Luna sample collections. Considering distance and TiO_2 concentrations, Mare Nectaris and Sinus Asperitatis are the most likely source regions for the VLT basalts found at the A16 site, with Theophilus as the likely source crater.

Luna 16-like high-Al basalts: The provenance of high-Al basalts is not easily determined. It must be done on the basis of their FeO and TiO_2 concentrations (global Al_2O_3 is too imprecise) which are not unique. Sinus Asperitatis and Mare Nectaris are the closest mare basalt flows with the proper FeO and TiO_2 ranges, with Theophilus again as a likely source crater. One of the high-Al basalts (60639,1; [5-6]) also resembles Apollo 11 high-Ti, low-K basalt [6]; thus, it could be from nearby Mare Tranquillitatis. High-Al basalt 60053,2-9 is more similar to A14 group 5 high-Al basalts (which are products of the PKT and likely Imbrium ejecta) than L16 high-Al basalts, which suggests a basin ejecta origin. Lack of mare basalt in the ARBs argues against delivery by the Imbrium event, and locations of flows of high-Al basalt within the PKT are unknown. With a TiO_2 concentration of ~2 wt %, either Mare Nectaris or Sinus Asperitatis could be possible source regions.

Conclusions: Low-Ti or VLT mare basalts found in the A16 sample collection are likely from Mare Nectaris or Sinus Asperitatis. Most, if not all, of the mare basalt found at the A16 site was transported there by post-basin lateral mixing, via small to moderate sized craters in the surrounding maria (e.g., Theophilus). The lack of mare basalt samples in the basin ejecta deposits at A16 site is further evidence that mare basalts were rare prior to 3.9 Ga.

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Sample	TiO_2	Al_2O_3	FeO	MgO	Mg'	CaO	Na_2O	Sc	Cr	Co	Ni	Ba	La	Ce	Sm	Eu	Tb	Yb	Lu	Hf	Ir	Th	mass
65703,09-13	0.6	n.a.	21.4	n.a.	n.a.	12.1	0.218	56.4	2150	21.6	<190	<30	1.2	3.9	1.10	0.47	0.32	1.90	0.282	0.84	<4	0.07	20.37
62243,10-22	0.8	11.9	18.66	10.1	49.0	11.8	0.188	59.8	3830	30.1	110	<50	2.0	5.6	1.34	0.39	0.34	1.84	0.282	0.96	<10	0.12	15.29
60053,02-09	2.0	15.4	17.92	3.4	25.3	14.3	0.342	60.3	900	20.8	<190	97	4.7	13.0	3.54	1.02	0.91	5.17	0.763	2.79	<5	0.41	23.81
60503,22-07	8.7	9.9	18.59	10.5	50.2	10.7	0.296	74.4	3750	43.4	130	<90	3.9	11.9	5.47	1.14	1.55	5.93	0.900	5.14	<15	0.21	56.79
60603,10-16	14.5	5.5	23.20	13.0	50.0	7.2	0.429	46.0	6160	57.4	<130	222	14.5	39.6	11.35	2.56	2.38	5.79	0.775	11.1	<6	1.55	33.94

Table 1: Selected major- and trace-element chemistry for the A16 mare basalts in this work. TiO_2, Al_2O_3, and MgO were obtained by modal recombination (60053,2-9), broad-beam electron microprobe analysis (EMPA; 60503,22-7), and fused bead EMPA (all others). All other elements by INAA. n.a. = not analyzed. Mg' = (modal MgO/(modal MgO+FeO))×100. Mass is in mg.